Exploring Innovative Applications of Photogrammetry Technology in Metaverse Libraries: A Case Study of the Yu Maohong Donated Collection at Xi' an Jiaotong University Library

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Abstract

Purpose/Significance: To facilitate the effective presentation of special collections in metaverse libraries, a streamlined and practical workflow for 3D modeling of physical special collections has been established, offering advantages including low cost, high efficiency, and operational simplicity.

Method/Process: Through photogrammetry, libraries can utilize conventional photographic equipment and software to rapidly generate high-quality 3D models. Using the special collection donated by Professor Yu Maohong at Xi' an Jiaotong University Library as a case study, photogrammetry was employed to perform image acquisition, data preprocessing, 3D modeling, and quality analysis of a brush pot, with a thematic database being established to facilitate the archiving, presentation, and promotion of special collection resources.

Results/Conclusion: The application of photogrammetry-based 3D modeling of special collections in metaverse libraries can strengthen the exhibition and dissemination power of physical special collections, enhance user engagement and reading interest, foster interaction and communication between libraries and users, and offer new perspectives and possibilities for libraries' cultural education services.

Full Text

Preamble

Exploring Innovative Applications of Photogrammetry Technology in Metaverse Libraries: A Case Study of the Yu Maohong Donated Collection at Xi' an Jiaotong University Library*

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Abstract

[**Purpose/Significance**] To enhance the presentation of special collections in metaverse libraries, this study establishes a streamlined workflow for 3D modeling of physical special collections, offering advantages of low cost, high efficiency, and operational simplicity. [**Methods/Process**] Using photogrammetric methods, libraries can utilize conventional photographic equipment and software to rapidly generate high-quality 3D models. Taking the collection donated by Professor Yu Maohong to Xi' an Jiaotong University Library as a case study, we applied photogrammetry to conduct image acquisition, data preprocessing, 3D modeling, and quality analysis of brush pots, and established a specialized database for archiving, revealing, and promoting these special collection resources. [**Results/Conclusion**] Employing photogrammetry for 3D modeling of special collections in metaverse libraries can enhance the display and dissemination capabilities of physical special collections, improve user engagement and reading interest, promote interaction and communication between libraries and users, and provide new perspectives and possibilities for cultural education services in libraries.

Keywords: Metaverse; 3D Modeling; Photogrammetry; Physical Special Collections
Classification Number: G250

Introduction

The metaverse represents a digital world built upon virtual reality technology that enables seamless connections between people, between people and objects, and between objects themselves, offering users immersive experiences and limitless interactive possibilities [1]. As an emerging technology, the metaverse has sparked a new trend across global industrial sectors [2], with nations actively deploying resources and investments [3]. China has also attached great importance to metaverse development, introducing a series of policy measures to support the practical application of metaverse technologies [4].

As institutions for information and cultural collection, dissemination, and services [5], the library community fully recognizes the need to actively explore the opportunities and challenges presented by the metaverse, leveraging its platforms and tools to provide users with richer and more diverse resource interaction experiences [6]. Physical special collections constitute an important component of library special collections, possessing unique historical, artistic, and academic value. However, due to their rarity, stringent preservation requirements, and limited display space, they are often difficult to utilize and exhibit fully. Traditional 3D modeling methods typically require substantial investment in physical scanning and model production, which has constrained the application scope of 3D modeling in libraries. Therefore, identifying a simple and practical method to transform library physical special collections into resources within metaverse libraries represents a worthwhile research question.

1.1 Related Practices in 3D Modeling of Physical Resources

The "metaversification" of library physical special collections refers to the transformation of these collections into digital resources within the metaverse through digitalization, 3D reconstruction, virtual reality, and other technical means, thereby enabling their exhibition, dissemination, utilization, and preservation. Currently, several renowned museums and libraries domestically and internationally have begun experimenting with converting their physical special collections into metaverse resources to enhance their influence and appeal. For example, the Louvre Museum announced in April of this year the completion of "comprehensive digitalization" of its 480,000 collection items and provides a virtual space called "Louvre Metaverse" on its website, allowing users to appreciate the museum' s artistic treasures online [7]. The British Museum also launched a virtual space called "British Museum Metaverse" in June of this year, enabling users to explore the museum' s history and culture in virtual reality [8].

Although museums appear to be more common adopters of 3D modeling technology while libraries are often perceived as preserving two-dimensional materials such as books and manuscripts, in reality, any collection preserved by libraries is not truly two-dimensional, particularly special collections. As Adi Keinan-Schoonbaert, Digital Curator of the British Library' s Hebrew Manuscripts Digitization Project, points out: "Libraries have more potential than people imagine to engage in 3D modeling" [9]. Currently, the British Library, National Library of Scotland, Cambridge Digital Library, and State Library of Queensland have all conducted 3D modeling and published portions of their special collections and printed materials [10]. Indiana University Libraries used 3D modeling technology to create and publish 3D models of Native American cultural heritage in their collections [11]. To enhance public understanding of various disciplines and related talents, Hong Kong Baptist University Library developed the HKBU Heritage platform using 360-degree interactive rotating images to display selected faculty and outstanding student works [12]. By utilizing 3D scanning technology, libraries can convert the shape, texture, and color information of physical resources into digital models, thereby improving their accessibility and visual effects for both cultural heritage preservation and exhibition as well as education and research.

Overall, numerous foreign institutions have begun experimenting with transforming physical special collections into 3D resources, achieving certain results. In contrast, China remains in the initial stages. Therefore, identifying a simple and practical method for 3D modeling of physical resources holds significant importance for empowering metaverse construction in Chinese libraries.

1.2 Photogrammetric 3D Modeling Methods for Physical Resources

Currently, 3D reconstruction of physical objects generally employs methods such as laser scanners [13] and structured light scanners [14] to obtain surface data, followed by software reconstruction and optimization to generate 3D models. These methods emit laser pulses and record their return delays to determine distance points, generating geometric shapes and textures of target object surfaces. This approach can replicate the shape and characteristics of physical objects to achieve digital preservation and exhibition [15]. However, such methods require sophisticated and expensive measurement instruments and technically generated 3D data, with costs and complexity that have historically limited the application scope of 3D modeling. With the development of new technologies in recent years, the creation and use of 3D data have become more widespread, and photogrammetry-based methods have significantly reduced the hardware and software costs of 3D data acquisition and processing [16]. Photogrammetry can utilize ordinary digital cameras to capture objects without requiring expensive professional equipment, and has been applied across various scales and scenarios from micro to macro, indoor to outdoor [17].

Photogrammetry is a technique that employs photogrammetric principles and technology to calculate the three-dimensional coordinates of spaces or objects by capturing at least two photographs from slightly different angles. By measuring the vertical (y-axis) and horizontal (x-axis) position changes of points in each photograph, the distance from the camera to the relevant object can be calculated, thereby generating depth (z-axis) data. Photogrammetry technology can generate highly detailed 3D data from hundreds of captured images, subsequently producing 3D models in polygonal mesh format.

Using photogrammetric methods, libraries can complete 3D reconstruction of physical resources without purchasing additional equipment, utilizing existing cameras or image data. For example, researchers at the University of Massachusetts used photogrammetry to create open-access models of live animals [18]; numerous 3D models of museum and library special collections published on the Sketchfab platform have also utilized photogrammetry for 3D modeling [10].

Although photogrammetry offers advantages of simplicity and practicality in 3D modeling, its application to library physical resources requires specialized workflows. For instance, digital acquisition of special collections must consider factors such as material, shape, and color of cultural artifacts, and the substantial data generated during digital acquisition requires transformation and management. Therefore, 3D modeling of library physical resources necessitates the development of corresponding workflows tailored to specific circumstances to ensure quality and efficiency in digital acquisition and 3D modeling. Xi' an Jiaotong University Library applied photogrammetry technology to the digital acquisition and 3D modeling of physical resources, specifically brush pots donated by Professor Yu Maohong, and developed an effective workflow based on the characteristics of the collection.

2 Digital Workflow for Professor Yu Maohong' s Donated Brush Pot Collection

The special collection of Professor Yu Maohong's brush pots primarily comprises over 400 precious brush pots donated by Professor Yu Maohong to the library. As tangible carriers of traditional Chinese culture, these collections embody the spiritual core of "completeness"and "harmony"in Chinese culture. These precious brush pots not only represent the essence of traditional Chinese culture but also constitute important components of Chinese calligraphy, painting, carving, and other art forms. Due to the large quantity and complex craftsmanship of these precious brush pots, the library employed photogrammetry, a reverse modeling method, to meet the requirements of digital acquisition and 3D modeling. This approach captures surface data of the precious brush pots through photographs taken from different angles, followed by software reconstruction and optimization to generate 3D models. This method can faithfully replicate the shape and characteristics of physical objects to achieve digital preservation and exhibition.

The fundamental photogrammetric method involves first capturing overlapping photographs from different viewpoints to obtain stereo image pairs. Using triangulation principles, corresponding points are measured on two or more photographs to calculate the spatial coordinates of arbitrary points on the object, thereby generating point cloud data. Subsequently, wireframe or surface models are generated based on the object' s three-dimensional coordinates, converting point cloud data into polygonal meshes and projecting textures from the original photographs onto the meshes to generate colored textures, forming photorealistic 3D models. Based on photogrammetric principles, the library constructed a 3D modeling workflow for physical collections, comprising four stages: image acquisition, data preprocessing, 3D reconstruction, and archiving/exhibition.

2.1 Multi-View Image Acquisition of Physical Resources

The quality of photogrammetric modeling depends on the identification of similar patterns between photographs; therefore, multi-angle comprehensive shooting strategies must be established for physical resource modeling. Multi-angle measurement of static objects can be achieved by photographers moving around the collection to capture photographs from various perspectives, or by placing the collection on a turntable and capturing images from a fixed camera position during rotation. Since photogrammetric 3D modeling requires overlapping regions between each photograph and avoidance of drastic changes in environmental lighting, the first method often results in certain differences in lighting environments and backgrounds around the object. Therefore, for multi-view image acquisition of physical resources, the second fixed-camera-position method was selected, with collections photographed in a studio to establish an efficient workflow.

[Figure 1: see original paper] Image Acquisition Environment Setup

To ensure lighting consistency across multi-angle shooting, the library established a small studio for multi-view image acquisition of physical resources. The studio includes a camera, tripod, background board, turntable, lighting equipment, and softboxes with reflector panels. The shooting equipment consists of a DSLR camera, with shutter speed, aperture, and ISO parameters adjusted to ensure captured images clearly reflect the details of the physical objects. To maintain constant camera position and angle, a tripod was used to secure the camera. The shooting target was placed on a turntable for uniform rotation, with the camera capturing images throughout at least one full rotation. After multiple shooting tests, the following shooting strategy for physical resources was determined:

2.1.1 Object Placement Strategy [Figure 2: see original paper] Object Placement Strategy Diagram

The quality of 3D modeling depends on comprehensive photography of both external and internal surfaces of physical resources. Simply shooting the object upright for one full rotation is insufficient, as cameras cannot capture the bottom and interior surfaces, often resulting in adhesion between the bottom and ground and insufficient internal depth in the modeling results. Therefore, for brush pot-type physical resources, at least three placement orientations are required during shooting: upright with opening facing upward, inverted with opening facing downward, and horizontal with opening facing outward. Shooting with the opening facing upward primarily captures details of the top and external surfaces; shooting with the opening facing downward primarily captures details of the bottom and external surfaces. In both cases, the camera employs a downward-tilting angle of approximately 15 degrees. Horizontal placement with the opening facing outward primarily captures details of the internal surfaces, with the camera angle parallel to the opening direction to observe interior surface details from various angles as much as possible. If a single horizontal shooting is insufficient to capture interior wall details from all directions, the model should be rotated and placed horizontally again to bring previously occluded interior walls into the camera' s field of view, with camera parameters readjusted and refocusing performed before shooting.

2.1.2 Lighting Environment Setup To ensure maximum lighting consistency across multi-angle shooting, surface light sources were employed. Surface light sources provide uniform illumination, ensuring each part of the object receives identical lighting. Additionally, reflector panels were placed around the softbox light sources within the shooting tent to reflect light back onto the object and fill any shadows, thereby ensuring consistent lighting between each photograph and facilitating subsequent 3D modeling processing.

The aforementioned lighting strategy can be applied to capture external surface images of brush pot-type physical resources. However, for the interior surfaces of brush pots with depth, ambient light sources are often insufficient to penetrate deeply. Inadequate lighting significantly affects the modeling quality of the object's interior. To address this issue, linear light sources were used for forward fill lighting from the camera's shooting angle to penetrate deeper into the brush pot interior and capture more details.

2.1.3 Background Environment Setup Photogrammetry requires appropriate environments, preferably using solid-color backgrounds for data acquisition while avoiding highly reflective materials such as glass partitions, ceramic tiles, and waxed floors. Furthermore, to prevent adhesion between the object and background during 3D modeling, background colors with strong contrast to the object should be selected. For example, white backgrounds for wooden brush pots, light yellow backgrounds for jade brush pots, etc., thereby highlighting the distinction between object and background. Particularly, maintaining certain color differentiation between the turntable and surrounding background colors will help determine the object's spatial structural relationships.

2.2 Image Data Processing

Upon completion of image acquisition for physical resources, each object corresponds to a set of videos captured from multiple angles during one full rotation. To generate images suitable for photogrammetric 3D modeling, the captured videos must be sampled. The number of sampled images cannot be too few, as photogrammetry requires sufficient overlap of object patterns between different angles to achieve corresponding point matching; nor should it be excessive —directly extracting every frame from the video would significantly increase computational complexity and risk overfitting and modeling failure. Through practical testing, for a turntable with a 30-second rotation period, sampling one image every 6 frames for 3D modeling proved appropriate.

To ensure modeling quality, image preprocessing should include noise removal and adjustments to brightness and contrast to improve subsequent processing effectiveness. These preprocessing steps help obtain clearer, more accurate images, thereby enhancing 3D modeling quality. For noise removal, image filters can be used to smooth images and eliminate noise. For brightness and contrast adjustment, techniques such as histogram equalization can enhance image contrast and brightness. These preprocessing steps improve image quality and increase the success rate of 3D modeling.

2.3 3D Reconstruction Process for Physical Resources

During the 3D reconstruction process, photogrammetry software can construct realistic 3D models from multiple photographs. This process involves several steps: first, capturing multiple photographs to cover the entire object surface; then using photogrammetry software to extract feature points from these photographs and calculate their relative positions; finally, converting these feature points into three-dimensional coordinates and generating the 3D model. Currently, various photogrammetry software packages support the 3D reconstruction process for physical resources, such as RealityCapture from CapturingReality, PhotoScan from Agisoft, and domestic software including Reconstruction Master and Cloud Earth.

Comparison of Common Photogrammetry Software

Software	Developer	Key Features	Limitations
RealityCapture	Capturing Reality (Czech Republic)	1. Can process large numbers of photos to generate high-quality 3D models. 2. Can automatically align photos, generate point clouds, add textures, etc. 3. Supports multiple 3D data formats.	Relatively complex operation requiring certain learning curve; higher price.
Agisoft PhotoScan	Agisoft LLC (Russia)	1. Simple operation, easy to learn. 2. Can process large numbers of photos to generate high-quality 3D models. 3. Can automatically align photos, generate point clouds, add textures, etc.	Lower fault tolerance for data processing, prone to errors. 3D effects have limitations.
Reconstruction Master	Wuhan Dashi Smart Technology Co., Ltd.	1. Supports ultra-large-scale real-scene 3D cluster modeling software. 2. Applies content-aware technology to improve modeling effects. 3. Supports multi-source data fusion reconstruction optimization.	While it can speed up reconstruction, it may cause file issues.

Software	Developer	Key Features	Limitations
Cloud Earth	Wuhan Dashi Smart Technology Co., Ltd.	1. Simple operation, easy to learn. 2. Supports multiple data format import and export. 3. Can be used in web browsers.	May experience lag in low-speed network environments; does not support offline use.

Based on actual modeling requirements and considering the advantages, disadvantages, and use cases of various photogrammetry software packages, Cloud Earth was selected for 3D modeling. This software employs cloud-based modeling: captured images are first uploaded to the cloud, the modeling process is completed in the cloud, and the final modeling results are downloaded to local computers. Compared with traditional modeling methods, cloud-based processing does not occupy local CPU and memory resources, requires no installation of modeling software, and allows modeling to be completed using office computers with cloud computing power.

The library’ s 3D reconstruction process for physical special collections using cloud-based modeling includes the following steps: register an account, set turntable mode, upload image data requiring reconstruction, and submit processing tasks. Upon task completion, a notification is sent to the account-bound mobile phone. The created 3D models can be previewed directly in web browsers and exported as OBJ format files. This process is highly convenient, requiring no professional background or setting of camera position and pose parameters to achieve efficient 3D modeling.

2.4 3D Model Quality Control and Archiving

After output, librarians carefully inspect each 3D model and compare it with the actual object to ensure modeling quality. As a reverse modeling method, photogrammetry inevitably produces noise and data gaps. When shooting angles, lighting environments, and background settings are not ideal, direct software modeling results cannot be used for archiving. Common issues include background adhesion, insufficient interior surface details, inadequate depth, and gaps. For each failure scenario, librarians have established supplementary shooting strategies for image acquisition and perform remodeling. In cases where the main model has minor flaws, manual repairs can be made using software without requiring complete remodeling. Therefore, for models with minor imperfections, the Blender tool is used for model adjustment.

[Figure 3: see original paper] Minor Flaw Models and Repair Effects

3D models generated through photogrammetry typically contain large numbers of polygons. To reduce processing time and difficulty, high-density 3D models must be decimated to simplify model structure. For flawed local meshes, guide curves conforming to the physical object' s surface can be created to quickly adjust edge layouts.

Photogrammetry software automatically creates texture maps from photographs. When topology meshes are recreated, texture mapping must be reassigned. After completing quality inspection of 3D models, they can be entered into the special collections database for unified archiving management, facilitating search, discovery, digital curation, and promotion.

3 Construction and Promotion of Professor Yu Maohong' s Donated Collection Database Using Metaverse Technology

To facilitate preservation of digital objects of physical collections, help users gain deeper understanding, discovery, interaction, and utilization of resources, integrate outstanding Chinese traditional culture into contemporary society, and inspire viewers' pride and identity with traditional culture, the library employed metaverse technology in 2022 to construct the Professor Yu Maohong Donated Collection Database. The specialized database achieves digital preservation and revelation of physical collection information, providing vivid introductions to physical collections for users.

3.1 Specialized Construction Based on a Universal Special Collection Resource Publishing Platform

Under traditional specialized database construction models, libraries must invest in construction individually for each distinctive resource, resulting in issues such as poor data reusability, high construction costs, and data silos. In the 2021 CADAL Co-construction and Sharing Project, Xi' an Jiaotong University Library undertook the construction of the CADAL Universal Special Collection Resource Publishing Platform, which supports libraries in publishing multiple special collection databases based on a single platform, providing publication and revelation for multi-type resources. Particularly for 3D model resources, it supports interactive experiences in computer or mobile browsers through the three.js plugin.

Based on this universal special collection resource publishing platform, the library constructed the Professor Yu Maohong Donated Collection Database, providing search and discovery, category navigation, digital exhibitions, and online interaction for over 400 collection items. According to the Song Dynasty ten-category classification system, collections are categorized into figures and portraits, flowers and birds, landscapes and rocks, immortals and deities, animals and insects, vegetables and herbs, minor scenes and miscellaneous paintings, architecture and boats, etc., with navigation portals for each category provided on the database homepage.

For archived digital physical resources, the system supports online browsing and opening of 3D models, allowing users to interact through zooming, scaling, rotating, and dragging, obtaining an online virtual experience comparable to viewing actual collections. By combining physical collections with metaverse virtual reality technology, physical entity resources can be published through virtual digital methods for display in metaverse libraries, providing users with diverse, engaging, and immersive experiences while protecting physical collections from damage due to human interaction, thereby enriching collection revelation methods.

3.2 Integration of Metaverse Collections with Digital Curation Under IIIF Technology

[Figure 4: see original paper] Professor Yu Maohong' s Donated Collection Database and Digital Collection Examples

As an open digital image protocol, IIIF technology has garnered widespread attention in the library, museum, and archive fields since its emergence in 2015 and has been extensively applied in digital curation processes. Traditional IIIF technology application models primarily display high-definition images of resources at the two-dimensional level. In metaverse libraries, digital collections can be combined with IIIF technology, utilizing IIIF to publish offline exhibition images and leveraging semantic annotation functions to achieve interactive annotation areas in digital exhibitions that link with digital collections, thereby obtaining effects that blend reality with virtuality and co-publish physical and metaverse exhibitions.

In the special collection platform, Xi' an Jiaotong University Library published the offline exhibition of Professor Yu Maohong' s special collection online and created annotation content for each specially introduced exhibit. Through IIIF' s semantic annotation function, users can click to open digital collection links while appreciating the exhibition to further examine collection details. Using digital technology to combine IIIF with digital twin objects enables cross-media narrative and digital curation of special collection resources, displaying their morphological characteristics, historical culture, and academic value to enhance user perception and experience.

3.3 Cultural Education Service Model Combining Metaverse Library Construction with Student Practice

[Figure 5: see original paper] 3D Collections in IIIF-Based Digital Curation

Regarding the librarian team, the Professor Yu Maohong Donated Collection Database was primarily constructed by a special working group composed of three departments: Resource Development, Information Technology, and the Library Office. Librarians from the Resource Development Department are responsible for metadata processing of special collection resources, including fine-grained tag management and data quality control. Librarians from the Library Office are responsible for photographing physical special collections and offline exhibitions and organizing information. Librarians from the Information Technology Department provide technical support for the platform, including transforming special collection resources into visualizable, searchable, and analyzable data.

[Figure 6: see original paper] Image Acquisition Process and Student Project Participation Experiences

As part of cultural education, the Professor Yu Maohong Donated Collection Database not only provides digital curation functions for collection promotion but also offers students hands-on opportunities to participate in 3D reconstruction. On one hand, learners as users of special collection resources can utilize these resources for self-directed learning and knowledge exploration; on the other hand, they can personally participate in the construction process of the special collection platform for practical training. For example, under the guidance and support of Information Technology Department librarians, students applied digital twin technology to 3D model the turntable-captured videos of collections from Professor Yu Maohong' s donated collection, achieving panoramic display of over 200 brush pots. Through participation in the special collection platform construction, learners can not only access, learn, and master digital technologies, enhancing their digital literacy and professional skills, but also expand their knowledge horizons and cultural cognition during the process of digital reorganization and digital curation, gaining deeper understanding of the historical and artistic value behind collections and appreciating their rich humanistic spirit and social significance. According to surveys, students participating in the 3D construction of special collections believe that the process not only developed their video processing and photogrammetric 3D modeling capabilities, enhancing their ability to apply metaverse technologies, but also provided aesthetic cultivation through the collections' unique shapes and brilliant colors, deepening their understanding of collection culture.

This paper thoroughly explores the application of photogrammetry technology in metaverse libraries and how to transform library physical special collections into resources within metaverse libraries. Using the brush pot modeling from Professor Yu Maohong' s donated collection at Xi' an Jiaotong University Library as a case study, we detail the relevant techniques and steps for video shooting and 3D modeling, demonstrating the effects and value of photogrammetry applications in metaverse libraries. This research not only provides new possibilities for the implementation and promotion of physical collections in metaverse libraries but also offers a novel perspective for cultural education within the metaverse vision.

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Note: Figure translations are in progress. See original paper for figures.